TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 32

CAUSES OF CRACKING OF IGNITION CABLE.

By
J. B. Dempsey
F. B. Silsbee,
Aeronautic Power Plants Section,

BUREAU OF STANDARDS.

February, 1921.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL NOTE NO. 32.

CAUSES OF CRACKING OF IGNITION CABLE.

By
J. B. Dempsey
F. B. Silsbee,
Aeronautic Power Plants Section,

BUREAU OF STANDARDS.

Resume.

NOTE:- The object of this resume is to present in brief and convenient form the salient facts of this report for the benefit of those who may wish to utilize the results of this investigation without studying the more detailed description of apparatus and methods.

The experiments described in this report show that the cracking at sharp bends, observed in the insulation of high tension ignition wires after service, is due to a chemical attack upon the rubber by the ozone produced by the electric discharge which takes place at the surface of the cable. This cracking does not occur if the insulating material is not under tension, or if the cable is surrounded by some medium other than air; but does occur even if the insulation is not subjected to electric stress, provided the atmosphere near the cable contains ozone. The extent of this cracking varies greatly with the insulating material used; and can be materially reduced by using braided cable and by avoiding sharp bends.

CAUSES OF CRACKING OF IGNITION CABLE.

High tension ignition cables, used to connect the spark plugs with the distributor blocks on internal combustion engines, occasionally give trouble by cracking of the insulation; which is particularly likely to occur at sharp bends in the cable. It has been found by manufacturers of ignition systems that a convenient test of the ability of a cable to give satisfactory service is obtained by wrapping the cable firmly around a metal mandrel and applying voltage from a magneto or spark coil between the core of the cable and the mandrel. Inferior quality cable will in the course of a few hours show cracks which begin at the outer surface and rapidly become deeper until a puncture of the insulation finally occurs through one of these cracks.

The Bureau of Standards was requested by the Bureau of Aircraft Production to locate more definitely the cause of this trouble, and for this purpose an extensive series of tests was made on three samples of ignition cable. Samples I and II were very kindly supplied for the test, by the Kerite Insulated Wire and Cable Company and were insulated with their Kerite compound. Sample III was rubber insulated with a mineral filler and had been furnished under Signal Corps Specification 28 003-A for High Tension cable. The properties of the materials are given in the following table:

TABLE I.

Sample Number	I	II	III
Insulation	Kerite	Kerite	Rubber
Braids	None	Two	Two
Conductors	19 # 26	12 # 26	19 # 29
Diam. over rubber	7.35 mm.	6.29 mm.	5.70 mm.
Diam. over all	7.35 mm.	7.64 mm.	7.07 mm.
Dielectric constant.	3.4	3.7	3.6
Set	5.7 %	4.6 %	16 %
Ultimate elongation	320 %	310 %	360 %
Eff. Dielectric Strength	56 500 v.	43 800 v.	40 600 v.

The majority of the tests were endurance runs, during which the specimen was subjected to a combined mechanical and electrical stress for a certain period of time. At the end of each of these tests, the samples which had not punctured were immersed in water for approximately 24 hours and then subjected to a breakdown test using 60 cycle A.C. voltage. The results of this test are given in Table II attached.

In this table, column II or III, gives the length of time that the sample was subjected to the electrical stress from either a magneto, running at about 2000 r.p.m. and firing a 6 mm. 3-point spark gap; or from a transformer, giving the voltage indicated in column IV at 60 cycles. Column V gives the medium surrounding the cable, and column VI the diameter of the arbor on which it was wrapped. Column VII states by "yes" or "no" whether or not failure occurred during the endurance test, and also the number of samples to which this statement applies. Column VIII states whether or not cracks were visible in the insulation at the end of the endurance test. Column IX gives the total length of time that the material had been soaked in water previous to the breakdown test. Column X gives the value of the effective 60-cycle breakdown voltage and is the average of results obtained upon the number of breakdown samples indicated in column XI. This table contains only data on failures which occurred in the center portion of the samples. All cases where there was any possibility of failure being produced by undue mechanical or electrical stress at the ends of the sample or at the surface of the water have been omitted.

It appears from this work that cracking is produced in substantially the same manner, but somewhat more rapidly, when the samples are tested on 10000 volts alternating current, than when tested on a magneto. The amount of the cracking is very materially reduced by the presence of the braid and is much less in the material having Kerite insulator than in that with the rubber. The cracking is entirely absent if the sample is left straight, or if no electrical stress is applied, or if surrounded by water or paraffin. The cracking is evidently a progressive phenomenon, requiring a combination of several factors, i.e., mechanical stress, electrification, and the presence of air.

The theory of this action, which successfully explains nearly all of the phenomena, was originally suggested by

Mr. Harris of the Kerite Company as follows: The electrification produces a brush discharge at the surface of the cable, which in turn produces ozone and oxides of nitrogen. This is shown by the noticeable odor after the endurance test has been run for some time and the visible glow surrounding the wires when in the dark. This glow is more prominent on the A.C. test and Figs. 1 and 2 are photographs of this taken with about 15 minutes' exposure at 13 000 volts. The electrical stress in the air at the surface of the cable, as computed from the dimensions of the wire and the dielectric constant, comes out much in excess of the breakdown strength of air and indicated that corona is to be expected.

It is well known that ozone actively attacks rubber; and when the rubber is under mechanical stress the products of the reaction are pulled apart, thus exposing at each incipient crack a fresh surface of rubber, which is in turn attacked. This effect doubtless is responsible for the fact that the action is localized in definite cracks when the material is under tension but does not penetrate the material when the rubber is unstressed.

That the presence of air is required is shown by the fact that no cracking occurred in any of the samples tested under water or when coated with paraffin. A series of tests were made to demonstrate the effect of the ozone by inserting samples of the cable in the bottom of a glass jar which was provided at the top with a pair of electrodes from which a high voltage brush discharge could be produced. The jar was sealed tightly and a discharge from the points maintained a copious supply of ozone. The results obtained with this apparatus are as follows:

<u>17 HOUR RUN</u>.

Kerite Tape:	No tension; no effect noticeable.
Kerite Tape:	100% elongation; deep cracks on exposed side, particularly near edges. Sample broke at grips.
Para Tape:	No tension; softened, became sticky, and curled slightly.
Para Tape:	50% elongation; wrapped on cable; cracked badly and fell apart.
Okonite Tape:	No tension; no effect.
Okonite Tape:	50% elongation; wrapped on cable; cracked badly and fell apart.

Three types of ignition cable laid straight in bottom of jar; no cracking.

One sample of each cable wrapped on 3/8" diameter arbor.

Kerite braided:	No cracks except at ends.
Kerite bare:	Badly cracked and rubber entirely stripped off.
Rubber:	Deep and regular cracks.

One sample of each cable wrapped on 1" diameter arbor:

Kerite braided:	No cracks except at end.
Kerite bare:	Small cracks on surface. One large crack which allowed half of insulalation to peel away.
Rubber braided:	Many rather shallow cracks.

138 HOUR RUN.

One sample of each cable wrapped on 3/16" diameter arbor and subjected to ozone:

Kerite braided: Cracked deeply and uniformly except where paraffin covered braid.

Kerite bare: Cracked and broke in small pieces, stripping from cable.

Rubber braided: Cracked deeply and uniformly.

Physical tests of samples of cable which had been resting loosely in the ozone tank for 138 hours showed no appreciable change in permanent set or in ultimate elongation as a result of the treatment. The breakdown strength (at the end of this ozone treatment) is given in the following table:

TABLE III

Sample	Before Ozone Test		After 138 hrs.in Ozone	
	Voltage	No. Samples	Voltage	No. Samples
Kerite braided	43 200	7	47 200	3
Kerite bare	56 500	4	50 100	3
Rubber braided	40 600	6	39 200	2

It will be noted that in specimens Nos. 1-4-9-18-21 (Table II) failure occurred during the endurance runs when there were no visible cracks and when the conditions were such that no cracks were to be expected. The maximum voltage applied to the specimen in these tests probably did not exceed 18 000 volts, which is a relatively small fraction of the breakdown strength of the unaffected cable, and these results imply a progressive deterioration of the material other than that due to cracking. These failures occurred only when bare samples were wrapped on the arbor, and did not occur with the braided material. Specimens Nos. 67 and 68 as compared with No. 50 for the mineral rubber cable indicate that such a deterioration takes place with this insulation. A comparison of specimens Nos. 26 and 27 with No. 25 show little, if any, effect of this nature in the Kerite.

A comparison of specimens Nos. 65 and 66 with No. 50, and No. 13 and No. 14 with No. 25 seem to indicate a deterioration in both classes of material when subjected to prolonged mechanical stress. The time required to produce these effects is long compared with that in which cracking develops in air, and they are therefore of less importance.

It was at first thought that the simultaneous application of mechanical and electrical stress might be the cause of the failures; but this is not the case, as shown by Table IV, which was obtained on Kerite insulation in the form of strips, and which shows no change great enough to account for the failure of the specimen at the low voltage applied during the endurance test.

TABLE IV.

	Without Tension	With Tension
Elongation	0	100 %
Thickness	.080	.056
Volts	33 400	26 700
Volts per mil.	420	480
No. of samples	12	9

A possible remedy for this trouble would be to cover the cable with a closely adhering coating of conducting material such as conducting paint or water soaked braid. This will prevent the tendency to form corona, as is shown in the photographs. It is, however, objectionable on account of the increase in the electrostatic capacity of the leads which results in a reduction of the maximum voltage produced by the ignition system, and also because most forms of conducting paint are liable to crack and produce at the cracks an excessive amount of corona. The use of an insulator having as small a value as possible for the dielectric constant is advisable as the voltage gradient in the air outside the cable is thereby reduced. There seems to be considerable difference in the rapidity with which different insulations are attacked chemically by the ozone. The ordinary impregnated braids help very materially in preventing cracking, probably because they are nearly air tight and prevent the ozone from reaching the rubber. After much bending, however, they will probably lose their efficacy. Supporting the cables on insulating materials at a distance from grounded conductors is beneficial in reducing the corona and also reducing the electrostatic capacity. It is, however, liable to cause inductive effects between the different cables, which may lead to the production of sparks in the wrong engine cylinder, unless the cables are placed apart from one another, as well as from the ground. The importance of carefully avoiding sharp bends in the wiring is very obvious.

It is to be concluded from this investigation, that the failure is caused by a chemical attack on the rubber by the products of the corona discharge; but is localized in cracks only where the insulation is subject to mechanical tension. Failure as the result of other causes, such as the combined application of mechanical and electrical stress, or the prolonged application of electrical stress alone, are shown to be absent or of minor importance.

TABLE II.

SUMMARY OF TEST OF HIGH TENSION CABLES.

K E R I T E   B A R E

I	II		III		IV	V
	ENDURANCE TEST					
Specimen No.	On Magneto Time Run Hours	Min.	On Transformer Time Run Hours	Min.	Voltage	Surrounding Material
1	2	0.0	-	-	-	Water
2	2	30.	-	-	-	"
3	31	0.0	-	-	-	Straight tube
4	0.0	25.	-	-	-	Water
5	7.	0.0	-	-	-	Air
6	2.	0.0	-	-	-	"
7	None	None	None	None	None	"
8	-	-	43	-	13,000	"
9	-	-	0.0	50	"	"
10	-	-	0.	30	"	"
11	-	-	1.	0	11,000	Water
12	-	-	5.	0	"	"
13	None	None	None	None	None	Air 158 hrs.
14	-	-	"	"	"	" " "
15	-	-	0	8	13,000	Air
16	-	-	0	9	"	"
17	-	-	0	19	"	"
18	-	-	1.0	0	"	"
19	-	-	33.	0	"	"
20	-	-	33.	0	"	"
21	-	-	25.	0	"	"
22	15	30.	-	-	-	Helix, paraffin
23	0.	45.	-	-	-	Helix, air
24	16.	30.	-	-	-	" "
25	None	None	None	None	None	-
26	-	-	156.	-	11,000	Water
27	-	-	326.	-	"	"
28	-	-	326.	-	"	Air

TABLE II (Cont'd)

SUMMARY OF TEST OF HIGH TENSION CABLES

KERITE BARE

I	VI	VII	VIII	IX	X	XI
Specimen No.	Diameter of Arbor	Failure with No. of Samples	Cracks	Hours Soaking in Water	Breakdown Voltage	No. of Samples Shot
1	One inch	Yes, 1	No	2.0	42,400	3
2	" "	No, 3	"	92	45,100	3
3	Infinite	No, 3	"	40	42,900	3
4	One inch	Yes, 1	"	-	-	-
5	" "	Yes, 1	Yes	24	-	-
6	" "	No, 3	No	None	42,300	3
7	" "	-	-	"	50,300	3
8	" "	No, 2	No	-	-	-
9	" "	Yes, 1	"	18	43,100	2
10	" "	No, 1	Yes	18	49,000	1
11	" "	No, 1	No	17	58,800	1
12	" "	No, 3	"	117	49,000	3
13	" "	-	"	18	47,700	3
14	3/32 "	-	"	18	37,000	2
15	3/8 "	Yes, 2	Yes	-	-	-
16	5/8 "	Yes, 2	"	-	-	-
17	13/16 "	Yes, 2	"	-	-	-
18	One "	Yes, 1	No	-	-	-
19	" "	No. 1	"	-	-	-
20	1 7/8 "	No, 1	"	-	-	-
21	" "	Yes, 1	"	-	-	-
22	7/8 "	No, 1	"	40	47,400	1
23	" "	Yes, 1	Yes	-	-	-
24	Infinite	No. 2	No	40	45,500	1
25	-	-	-	24	56,500	4
26	Infinite	No, 3	No	156	48,900	3
27	"	No, 3	"	326	52,000	3
28	"	No, 3	"	30	52,400	2

TABLE II (Cont'd)

SUMMARY OF TEST OF HIGH TENSION CABLES

K E R I T E   C O V E R E D

I	II		III		IV	V
	ENDURANCE TEST					
Specimen No.	On Magneto Time Run Hours	Min.	On Transformer Time Run Hours	Min.	Voltage	Surrounding Material
30	None	None	None	None	None	--
31	2	0	-	-	-	Water
32	38	0	-	-	-	"
33	31	0	-	-	-	Straight tube
34	19	0	-	-	-	Water
35	7	0	-	-	-	Air
36	-	-	0	50	13,000	"
37	-	-	0	30	"	"
38	-	-	16	0	11,000	Water
39	-	-	90	0	"	"
40	-	-	366	0	"	Air
41	-	-	156	0	"	Water
42	-	-	326	0	"	"
43	-	-	326	0	"	Air

M I N E R A L   R U B B E R

I	II		III		IV	V
50	None	None	None	None	None	-
51	2	0	-	-	-	Water
52	30	0	-	-	-	"
53	31	0	-	-	-	Straight tube
54	19	0	-	-	-	Water
55	7	0	-	-	-	Air
56 (	-	-	-	30	13,000	"
57 (	-	-	-	55	"	"
58	-	-	-	45	"	"
59 (	-	-	-	30	"	"
60 (	-	-	-	4	"	"
61 (	-	-	-	18	"	"
62	-	-	16	0	11,000	Water
63	-	-	90	0	"	"
64	-	-	-	5	"	Air, no braid
65	-	-	-	-	-	-
66	-	-	-	-	-	-
67	-	-	156	-	11,000	Water
68	-	-	326	-	"	"
69	-	-	326	-	"	Air

TABLE II (Concluded)

SUMMARY OF TEST OF HIGH TENSION CABLES.

K E R I T E   C O V E R E D.

Specimen No.	Diameter of Arbor	Failure with No. of Samples	Cracks	Hours Soaking in Water	Breakdown Voltage	No. of Samples Shot
30	-	-	-	24	43,800	7
31	One inch	No, 3	No	2	39,600	3
32	" "	No, 3	"	92	40,800	3
33	Infinite	No, 1	"	40	42,900	2
34	One inch	No, 3	"	19	44,300	3
35	" "	No, 3	"	24	36,800	2
36	" "	No, 3	"	18	43,100	2
37	" "	No, 3	"	18	40,800	3
38	" "	No, 3	"	17	47,800	3
39	" "	No, 3	"	117	45,500	3
40	" "	No, 9	"	30	46,000	9
41	Infinite	No, 3	"	156	41,100	3
42	"	No, 3	"	326	43,000	3
43	"	No, 3	"	30	45,100	2

M I N E R A L   R U B B E R

Specimen No.	Diameter of Arbor	Failure with No. of Samples	Cracks	Hours Soaking in Water	Breakdown Voltage	No. of Samples Shot
50	-	-	-	24	40,600	6
51	One inch	No, 3	No	2	35,600	3
52	" "	No, 3	"	92	32,900	3
53	Infinite	No, 1	"	40	37,900	3
54	One inch	No, 3	"	19	36,200	3
55	" "	No, 3	Yes	24	23,600	3
56	" "	Yes, 2	"	-	-	-
57	" "	Yes, 1	"	-	-	-
58	" "	Yes, 2	"	18	29,600	2
59	" "	No, 1	"	18)	)	
60	" "	Yes, 1	"	18)	34,500)	3
61	" "	Yes, 1	"	18)	)	
62	" "	No, 3	No	17	32,500	3
63	" "	No, 3	"	117	37,000	3
64	" "	Yes, 1	Yes	-	-	-
65	3/32",158 hrs.	-	-	18	28,000	2
66	1 ",158 hrs.	-	-	18	37,200	3
67	Infinite	No, 3	No	156	31,800	3
68	"	No, 3	"	326	25,500	3
69	"	No, 2	"	30	43,700	3

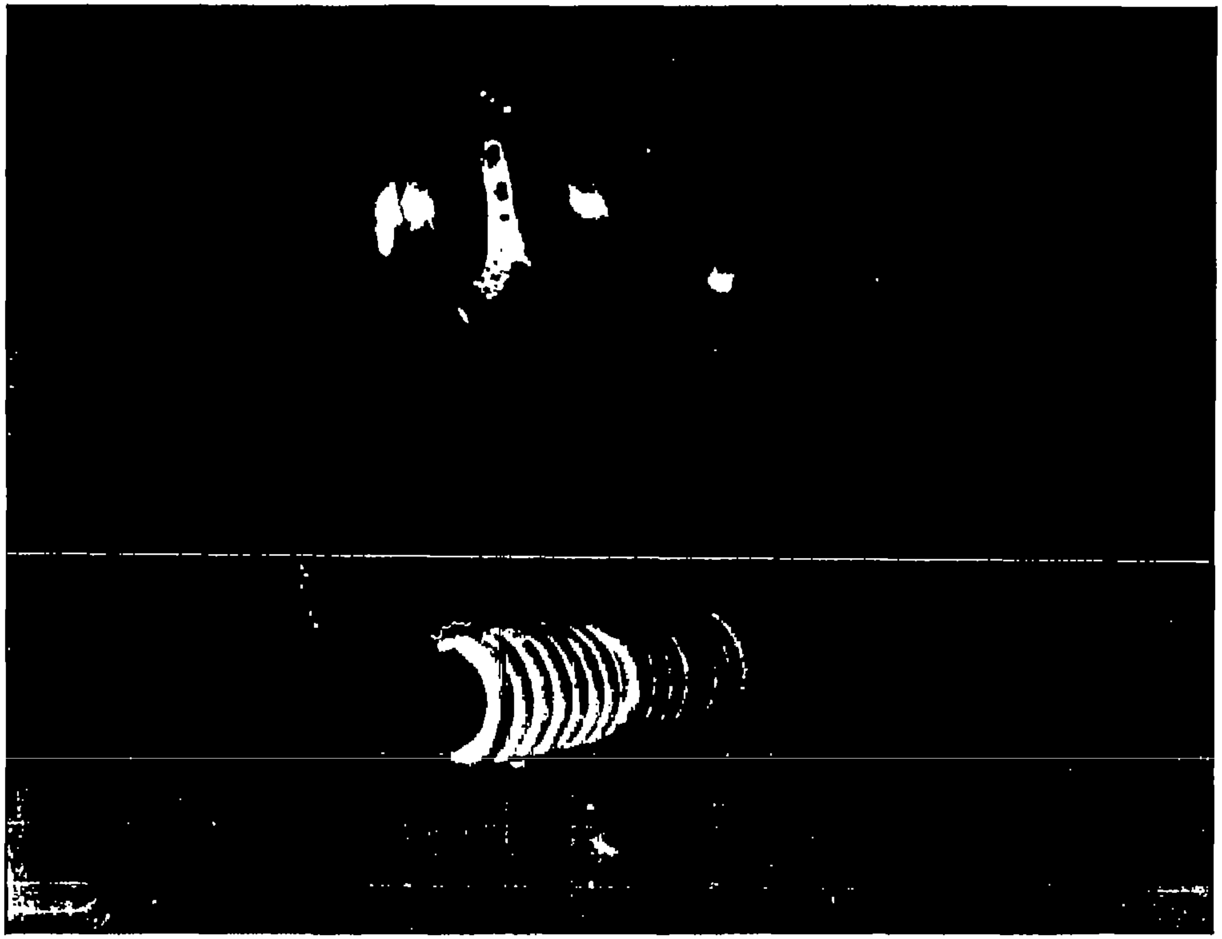

FIG. 1.—*Corona on ignition cables on 1-inch arbor. Exposure to corona only 20 minutes at 13 200 volts A. C.*

Upper mandrel from left to right: Kerite bare, mineral rubber, kerite covered. All three specimens covered with conducting paint, except at lower ends where corona appears.

Lower mandrel from left to right: Kerite bare, kerite covered, mineral rubber. Specimens untreated.

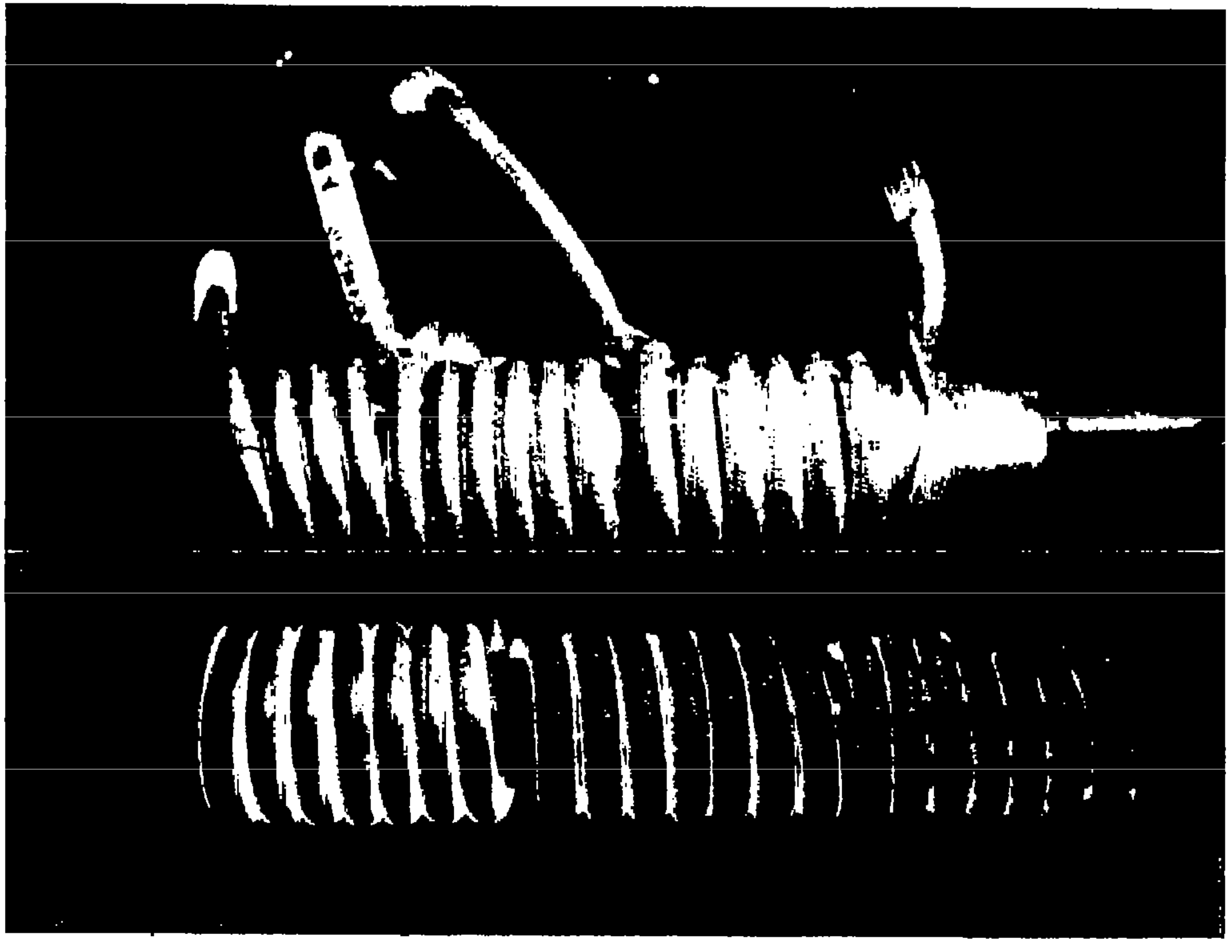

FIG. 2.—*Corona on ignition cables on 1-inch arbor. Exposure to corona only 15 minutes at 13 200 volts A. C. and to artificial light 5 seconds to show location of discharge.*

Upper mandrel from left to right: Kerite bare, mineral rubber, kerite uncovered.
Lower mandrel from left to right: Kerite bare, kerite covered, mineral rubber.